NASA TECHNICAL NOTE

c. 1

NASA TN D-5148

INVESTIGATION OF A CLASS OF BODIES THAT GENERATE FAR-FIELD SONIC-BOOM SHOCK STRENGTH AND IMPULSE INDEPENDENT OF BODY LENGTH AND VOLUME

by Raymond L. Barger and Frank L. Jordan, Jr.

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1969

NASA TN D-5148

INVESTIGATION OF A CLASS OF BODIES THAT GENERATE

FAR-FIELD SONIC-BOOM SHOCK STRENGTH AND IMPULSE

INDEPENDENT OF BODY LENGTH AND VOLUME

By Raymond L. Barger and Frank L. Jordan, Jr.

Langley Research Center
Langley Station, Hampton, Va.

INVESTIGATION OF A CLASS OF BODIES THAT GENERATE

FAR-FIELD SONIC-BOOM SHOCK STRENGTH AND IMPULSE

INDEPENDENT OF BODY LENGTH AND VOLUME

By Raymond L. Barger and Frank L. Jordan, Jr.
Langley Research Center

SUMMARY

A study has been made of a design method which provides a means of continually increasing the volume of a body without increasing the maximum overpressure or impulse. A sequence of three sonic-boom-generating bodies having length ratios of $1 : 2.5 : 4$ and volume ratios of $1 : 7.6 : 16.6$ was designed and tested. The results of the experiments, together with theoretical considerations, indicate that in the far field, the essential signature characteristics (maximum overpressure and impulse) are virtually the same for all three bodies.

INTRODUCTION

Sonic-boom effects may be alleviated by means of a favorable distribution of the volume and lift of the disturbing body. The goal of most sonic-boom minimization studies, simply stated, is to provide design methods to minimize overpressure and/or impulse for a given body volume. The approach to the problem used in this investigation provides a means of continually increasing the volume of a body without increasing the maximum overpressure or impulse.

Although this process can theoretically be carried out without limit, a practical limitation is imposed by the increased fineness ratio associated with the volume addition. The design method utilizes the favorable properties of a special type of F-function, and employs the procedure of reference 1 in describing the required body shape. The experimental verification consists of wind-tunnel measurements of the signatures of a sequence of three bodies designed by this method.

This method was applied to a study of volume effects alone in this investigation, but, at least in theory, it is also applicable to lift effects, inasmuch as such effects can be represented by an equivalent body (ref. 2).

SYMBOLS

p	local static pressure
p_∞	free-stream static pressure
x	distance measured along longitudinal axis from body nose
F(y)	Whitham's F-function
y	independent variable

THEORETICAL CONSIDERATIONS

The usual far-field pressure signature produced by a body in supersonic flight has the classical N-wave shape (ref. 3). When volume effects alone are considered it appears reasonable that the greater the volume of the body, the greater the boom disturbance that it creates. However, such is not necessarily the case, as will be shown by the following discussion.

Consider a body of such a size and shape that, for a given standoff distance, the impulse and maximum overpressure of its N-wave signature (fig. 1) are, according to some standard, considered acceptable. It is assumed that this generating body has a pointed nose with attached shock and also possesses other reasonable aerodynamic properties.

Now consider the signature of figure 2. It has the same boom characteristics as the first signature except that the positive and negative portions of the signature are separated by a section of zero overpressure. By means of the procedure described in reference 1 it is possible to derive the shape of a body that will generate this signature. Such a shape is not unique; on the contrary, there is a considerable degree of arbitrariness in the design of the nose and tail sections. A simple solution to the question of the appropriate nose shape is to use that of the original body, since that shape is known to generate the desired positive portion of the signature and to possess desirable aerodynamic properties. This is accomplished mathematically by making the F-function of the new body match that of the original body up to the beginning of the negative section.

The problem of designing the rearward portion of the body requires somewhat more discussion. The section of zero overpressure in the desired signature corresponds to a section of zero overpressure in the F-function and to a section of increasing diameter in the body shape. Then to reduce the diameter at the tail in order to provide a practical base area requires a considerable expansion, so that the zero section of the F-function

2

will in general be followed by a negative portion having significantly greater area than the initial positive section of the F-function. However, according to reference 3 the net integral of the F-function must be zero for any body whose wake eventually has constant area. Therefore the negative part of the F-function must be succeeded by a second positive section having area just sufficient to balance the positive and negative areas.

Consequently, in the near field, the strength of the tail wave will be considerably greater than that of the nose wave, and this effect will be greater for the second body than for the original body. However, inasmuch as the wavelets associated with the negative overpressure region regress (relative to wavelets associated with the zero overpressure section) into the tail shock, whereas the wavelets associated with the recompression region advance into the tail shock, there is a rapid cancellation in the near field of the effect of the recompression region. The result in the far field is a signature having essentially one positive section and one congruent negative section. This cancellation effect is observed in actual flight tests with airplanes whose signatures display significant recompression in the near field, but it invariably indicates N-wave type signatures in the far field (except for distortions produced by turbulence). (See ref. 4.)

One question to be considered in connection with this procedure is whether there would be another, perhaps preferable, method of modifying the middle section of the F-function instead of making it identically zero. For example, one might insert, after the initial positive part of the F-function, a negative part followed by a positive part of equal area, faired into the original negative region at the tail. (See fig. 3.) Such an example is discussed in reference 3. The shock that would form between the negative lobe and the succeeding positive lobe would diminish in strength at a faster rate than the nose and tail shocks, so that the far-field signature would resemble that of figure 2, with a relatively weak shock in that region which, in figure 2, is essentially zero.

Another possibility would be to design the middle section of the F-function so as to have two pairs of alternating negative and positive lobes instead of one. Then the near-field signature would have two rapidly decaying subsidiary shocks.

One can conceive of many such schemes to modify the middle section of the F-function. However, it can be demonstrated mathematically (see ref. 5) that all such modifications result in bodies having less volume than that corresponding to the F-function with identically zero middle section.

In order to demonstrate analytically the advantage of the method used in this investigation, a sample computation was made for a parabolic body having the same length and volume as the test body B described in the following section. The calculated signatures for the two bodies are shown in figure 4. It is seen that in the very near field (fig. 4(a)) the test body produces a slightly greater nose-shock overpressure than the parabolic body.

However, in the far field (fig. 4(b)) both the maximum overpressure and impulse are significantly less for the test body.

APPARATUS AND PROCEDURE

In order to obtain an experimental indication of the validity of the preceding theoretical considerations, wind-tunnel tests were conducted to obtain the generated pressure signatures from three appropriately designed bodies of revolution.

Shown in figure 5 are drawings of the three models (bodies of revolution) used to generate the pressure fields. The ratios of the lengths of models B and C to that of model A are 2.5 and 4, respectively. The ratios of the volumes of models B and C to that of model A are 7.6 and 16.6, respectively. The shapes for the three models were designed to produce pressure signatures having the following properties. The signatures generated by models B and C were to have the same magnitudes of maximum overpressure and impulse in their initial positive sections as the signature generated by model A. Further, the signature generated by model A was to have no region of zero overpressure between the initial positive and succeeding negative lobes, whereas the signatures generated by model B and model C were to have progressively longer regions of zero overpressure.

The tests were conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 1.41 and a Reynolds number per meter of 7.74×10^6. Measurements of the pressure field were made at orifices in a miniature conical probe having a 1.5° included angle. A reference probe, similar in design to the measurement probe, was located in a disturbance-free region of the stream flow and the difference in the pressures sensed by the two probes was measured by calibrated Statham gages having ranges of 1.72 and 0.69 kN/m^2 and an accuracy of 1 percent of the full range.

The measurement procedures incorporated wind-tunnel sonic-boom testing techniques described in reference 6 for eliminating or reducing extraneous influences in the measured pressures. The models and pressure-measurement probes were sting mounted on a remotely controlled support system which provided longitudinal motion capability for the models and lateral motion capability for the probes. By moving the models, the generated pressure disturbance was made to traverse the measuring orifice, which was maintained stationary at a constant lateral distance from the model for a given pressure signature. One disadvantage of this arrangement was the fact that the model support system was mounted on a solid window-blank in the test-section wall, making schlieren flow visualization impossible.

RESULTS AND DISCUSSION

The calculated and experimental signatures for the three bodies are shown in figure 6 for standoff distances of 38 cm and 94 cm. In terms of body lengths, the smaller distance represents 7.5, 3, and 1.88 lengths, respectively, whereas the larger distance is 18.5, 7.4, and 4.63 lengths.

It is seen that the calculated and experimental signatures are in reasonably good agreement. However, for the purpose of demonstrating the advantage of the design procedure, it may be more appropriate to compare the measured signatures with each other.

At the 38-cm station the peak nose-wave overpressures are within 7 percent of their average value, whereas at the 94-cm station they are within 4 percent of the average. The values of the impulse of the front portion of the shock are within 5 percent of their average value at the 38-cm station and within 4 percent of the average at the 94-cm station.

Similar examination of the experimental data applicable to the tail shock and impulse does not lead to meaningful results for these near-field measurements. However the relatively good agreement of experiment and theory tends to support the validity of the design concept.

The fact that the measured position of the tail wave was somewhat rearward of the calculated value may be attributable to boundary-layer phenomena. Boundary-layer behavior may also account for the cusp that occurs in the negative part of the signature for the two larger bodies. However, in view of the fact that this part of the signature is extremely sensitive to the body shape, it is possible that such an effect might also be caused by a machining deviation such as a straight, rather than a curved, fairing through the inflection point in the body surface near the base.

In any case these discrepancies near the tail shock disappear in the far field (as discussed in the section on theoretical considerations), and the negative part of the signature approaches a shape congruent with the initial positive section.

CONCLUDING REMARKS

Theoretical considerations indicate that it is possible to modify the shape of a body that produces acceptable far-field sonic-boom characteristics so as to increase the volume of the body significantly without increasing the far-field overpressure or impulse.

Wind-tunnel measurements of the near-field signatures of three bodies designed in accordance with such considerations tend to support this conclusion.

Boundary-layer effects appear to have a significant influence on the rear portions of the near-field signature of the longer bodies.

Langley Research Center,
  National Aeronautics and Space Administration,
    Langley Station, Hampton, Va., February 11, 1969,
      720-01-00-25-23.

REFERENCES

1. Barger, Raymond L.: Design of Bodies to Produce Specified Sonic-Boom Signatures. NASA TN D-4704, 1968.

2. Walkden, F.: The Shock Pattern of a Wing-Body Combination, Far From the Flight Path. Aeron. Quart., vol. IX, pt. 2, May 1958, pp. 164-194.

3. Whitham, G. B.: The Flow Pattern of a Supersonic Projectile. Comm. Pure Appl. Math., vol. V, no. 3, Aug. 1952, pp. 301-348.

4. Hubbard, Harvey H.; Maglieri, Domenic J.; Huckel, Vera; and Hilton, David A. (With appendix by Harry W. Carlson): Ground Measurements of Sonic-Boom Pressures for the Altitude Range of 10,000 to 75,000 Feet. NASA TR R-198, 1964. (Supersedes NASA TM X-633.)

5. Jones, L. B.: Lower Bounds for Sonic Bangs. J. R.A.S. (Tech. Notes), vol. 65, no. 606, June 1961, pp. 433-436.

6. Carlson, H. W.; and Morris, O. A.: Wind-Tunnel Sonic-Boom Testing Techniques. J. Aircraft, vol. 4, no. 3, May-June 1967, pp. 245-249.
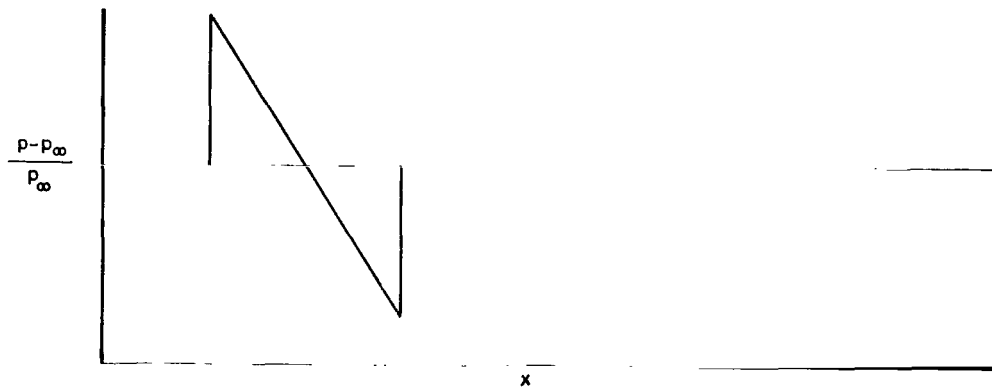
Figure 1.- Characteristic N-wave signature.
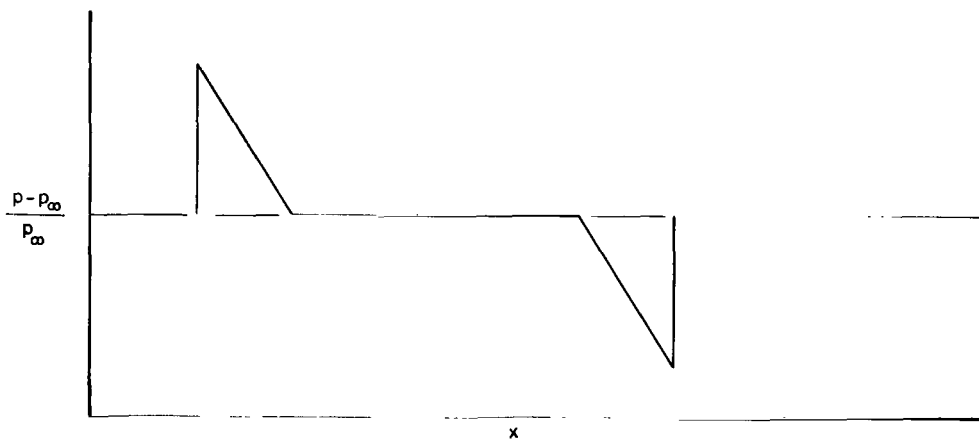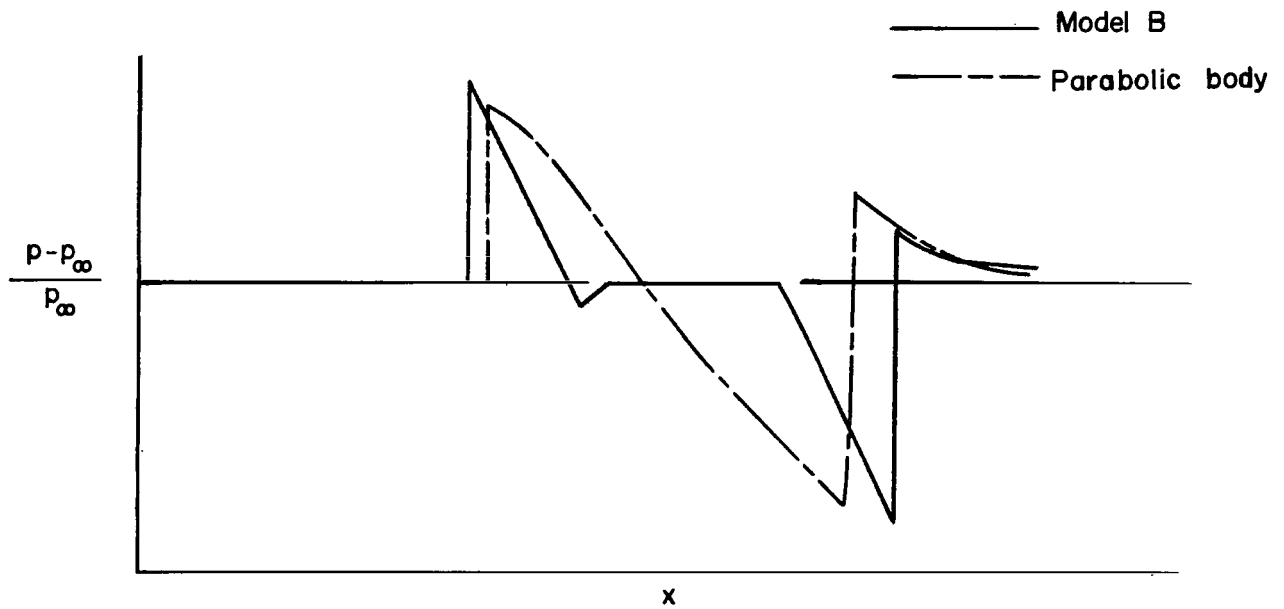

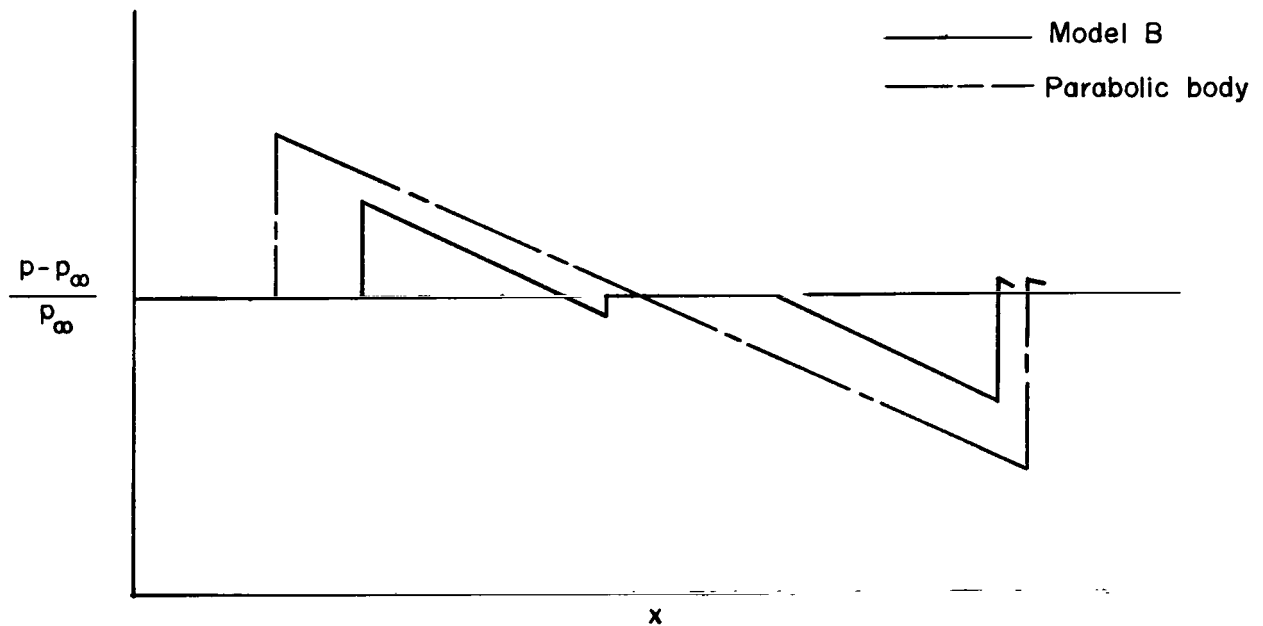Figure 2.- Modified N-wave signature.
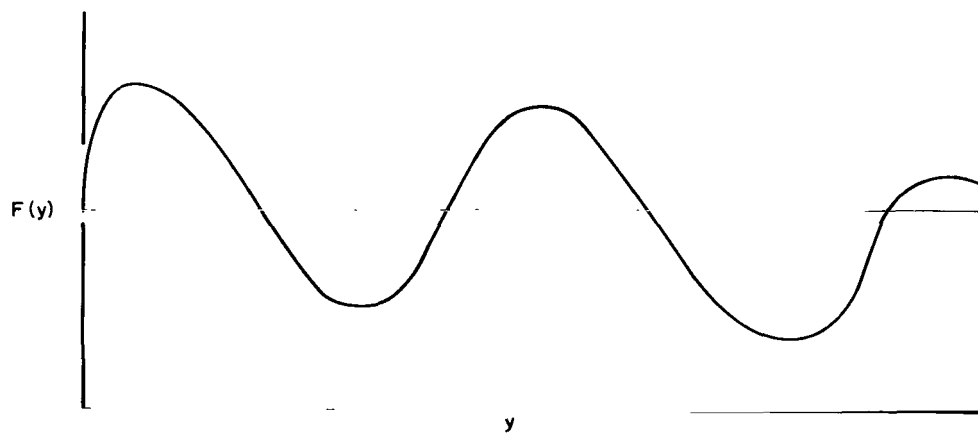
Figure 3.- Whitham's example of an F-function that does not produce a far-field N-wave signature (from ref. 3).
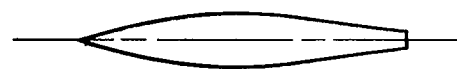
7

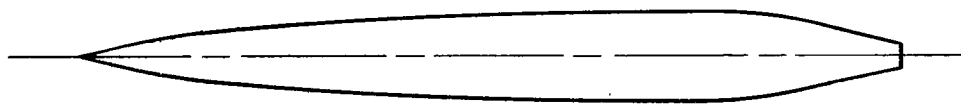(a) Standoff distance of one body length.
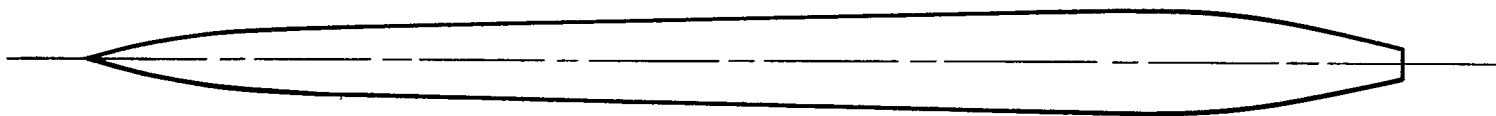

(b) Standoff distance of 100 body lengths.

Figure 4.- Comparison of signatures of test model B with those of a corresponding parabolic body.
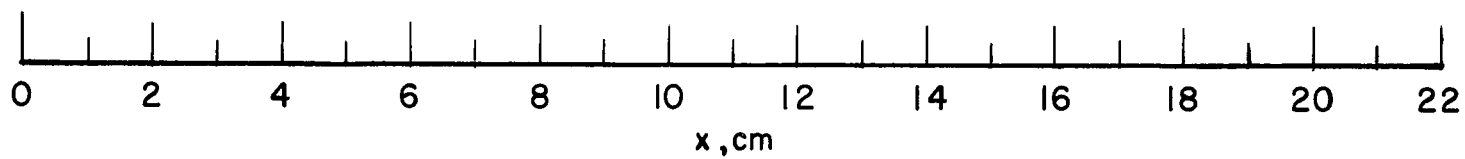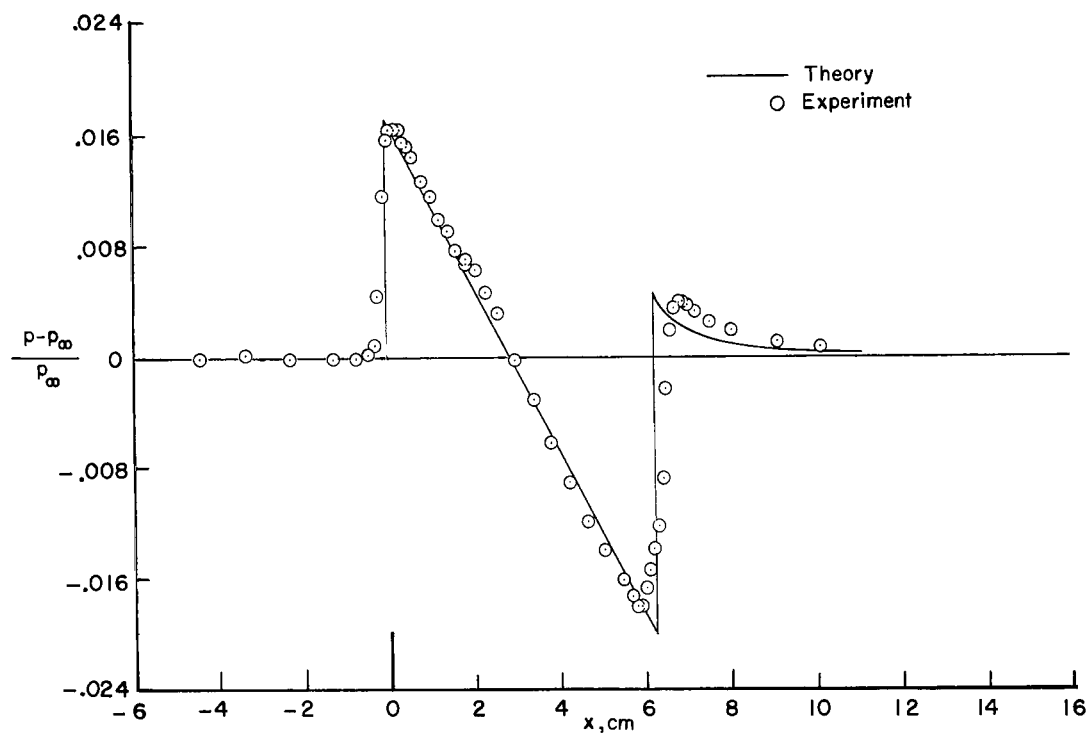
Model A

Model B

Model C

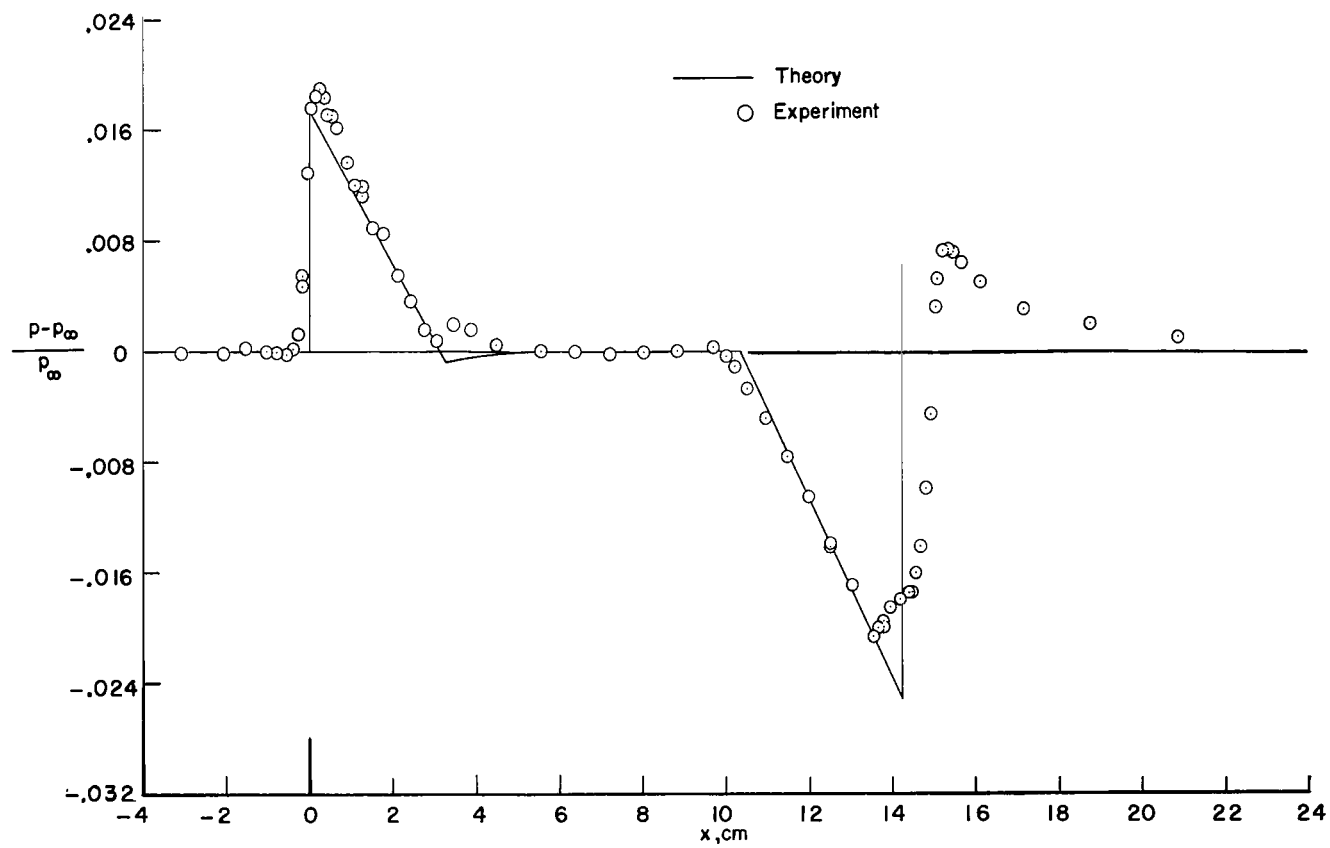|											
O	2	4	6	8	IO	I2	I4	I6	I8	20	22

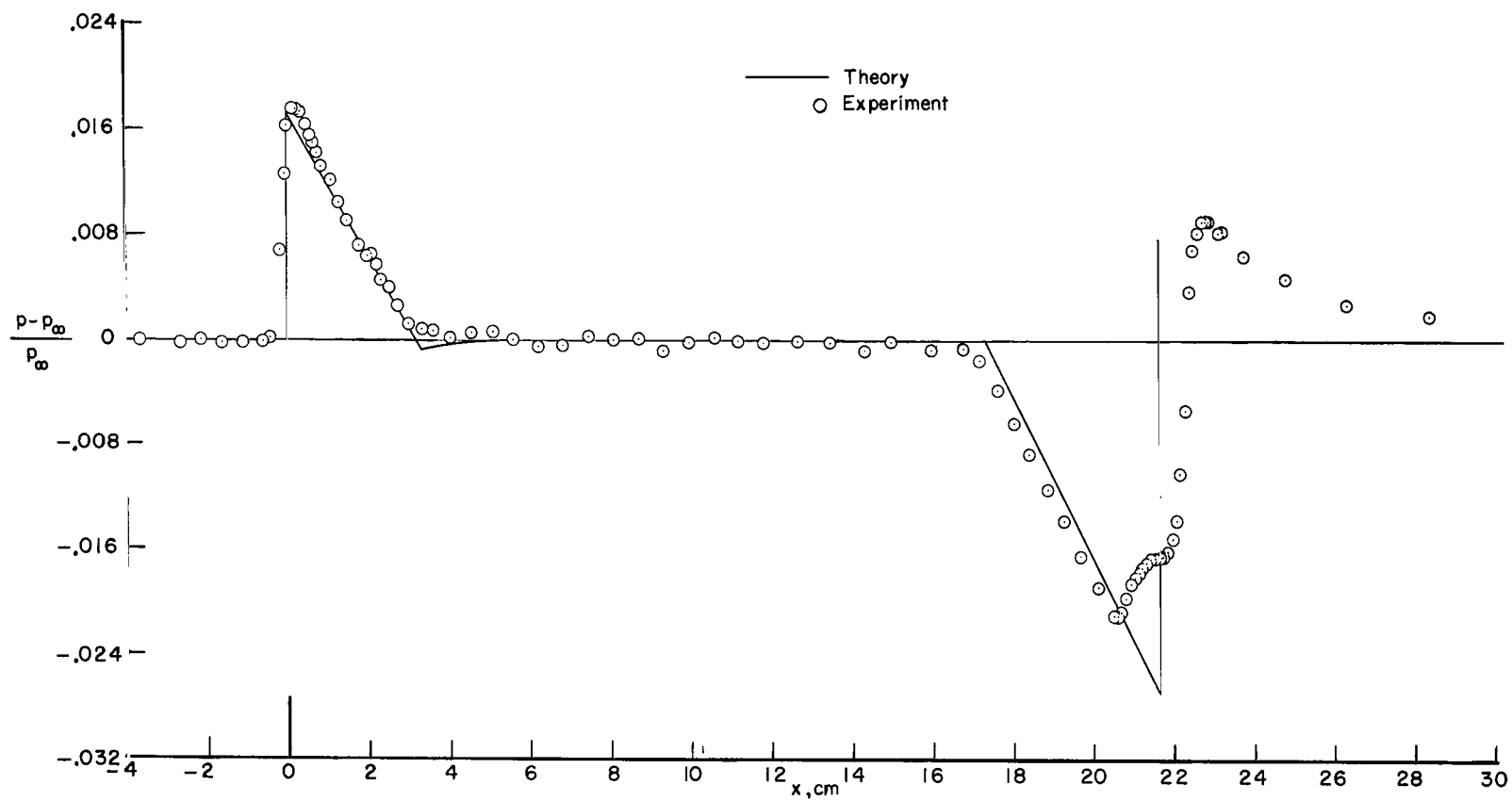x ,cm

Figure 5.- Test bodies.

(a) Model A. Standoff distance of 38 cm.

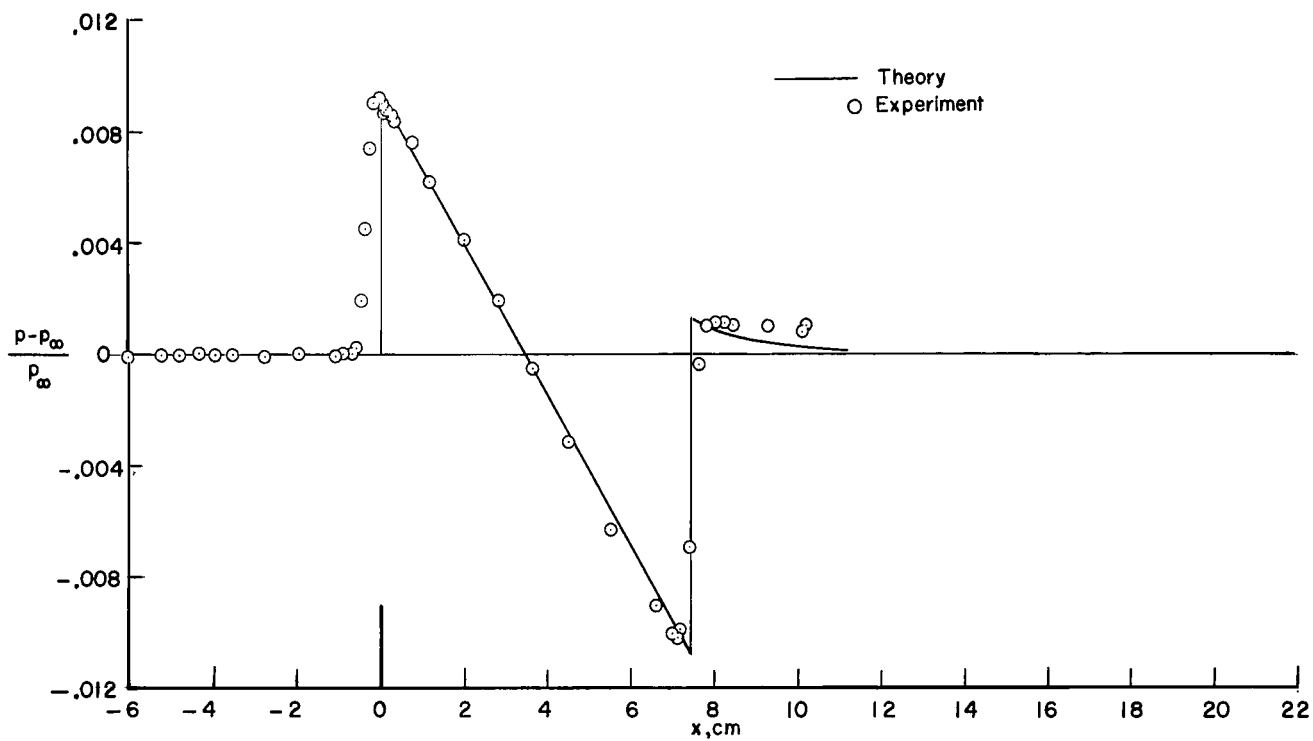Figure 6.- Calculated and experimental pressure signatures.

(b) Model B. Standoff distance of 38 cm.
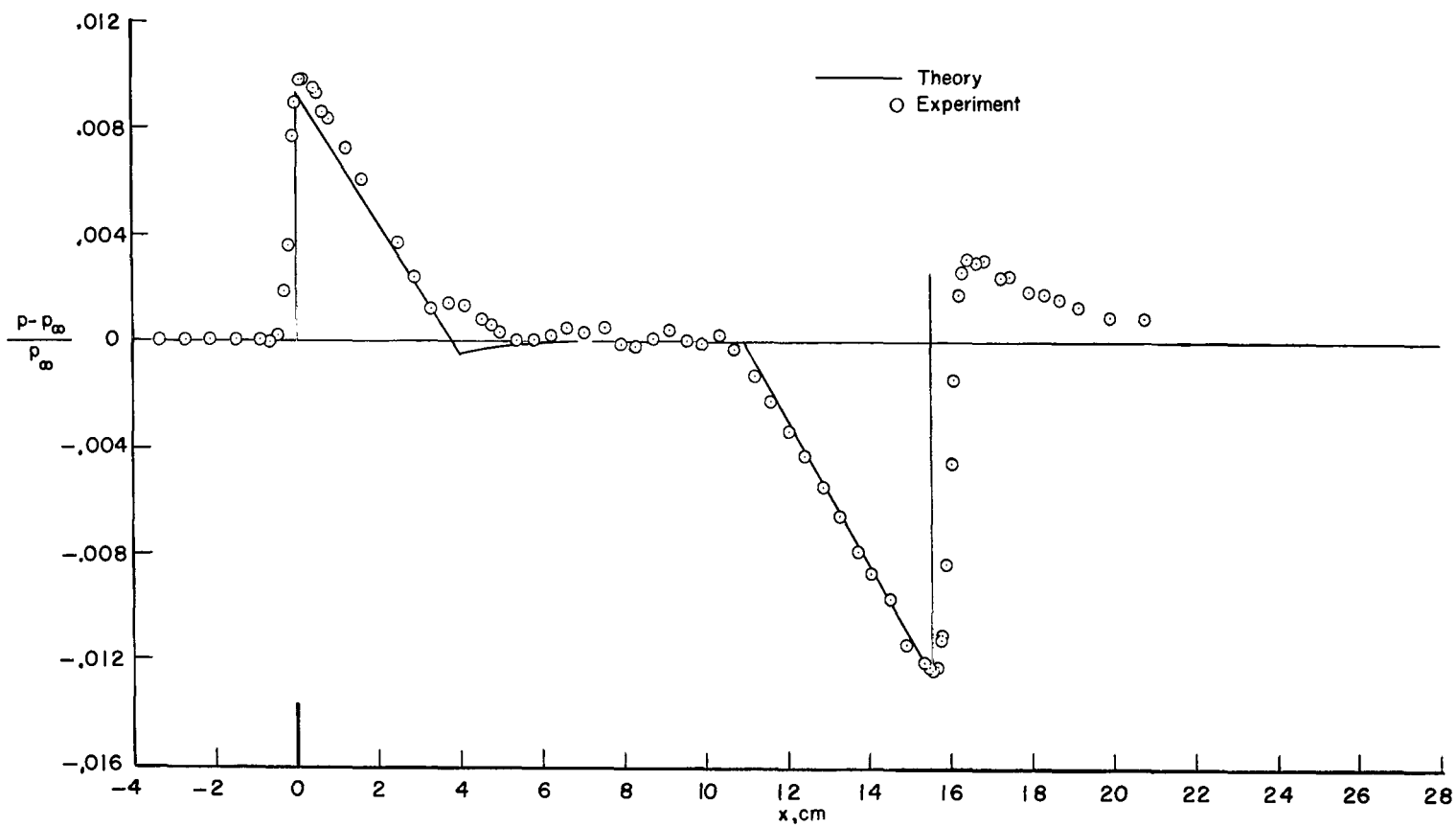
Figure 6.- Continued.

(c) Model C. Standoff distance of 38 cm.

Figure 6.- Continued.

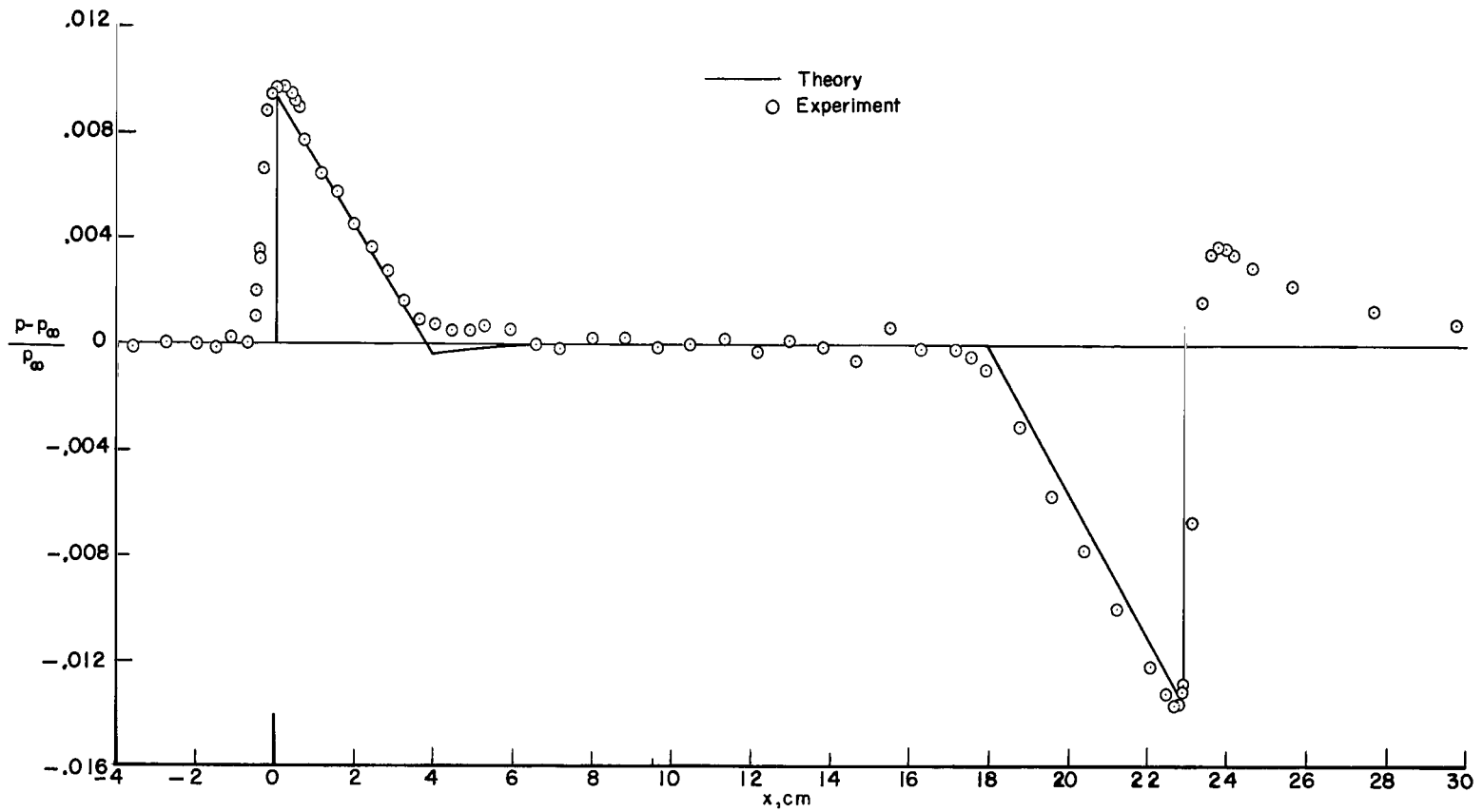(d) Model A. Standoff distance of 94 cm.

Figure 6.- Continued.

(e) Model B. Standoff distance of 94 cm.

Figure 6.- Continued.

(f) Model C. Standoff distance of 94 cm.

Figure 6.- Concluded.

U7U JO1 27 51 30S   69120 u0903
AIR FURCE WEAPONS LABORATORY/AFWL/
KIRTLAND AIR FORCE BASE, NEW MEXICO 8711

ATT ' LOU BLOWMAN, ACTING CHIEF TECH. LI

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546